AD A030075

LETTER REPORT COVER SHEET

PROJECT TITLE	PROJECT NO.	REPORT NO.	DATE	TYPE
Role of Head-Up Display in Instrument Flight	IFC-SP-76-1	IFC-LR-76-2	18 Aug 76	[ ] INTERIM [X] FINAL

REPORT

INTRODUCTION

The Tactical Air Command (TAC) and Aerospace Defense Command (ADC) have requested USAF Instrument Flight Center (USAFIFC) include Head-Up Display (HUD) information in Air Force Manual 51-37. The TAC and ADC requests are of extreme importance since HUD systems are presently installed in the A-7D, A-10, F-15, and F-111D aircraft and there is an expanding emphasis toward installing HUD systems in future aircraft. The role of HUD in an instrument environment must be defined to ensure its optimum operational utilization during various instrument flight regimes. At present, very little definitive data is available to establish or publish a standardized set of HUD procedures and techniques. Valid information on the use of the HUD in instrument meteorological conditions must be provided to Air Force pilots to assure standardization and enhance safety throughout the Air Force. In view of these factors, the IFC/RD conducted a pilot factors survey to determine: was conducted

1. (1) The present use of HUDs during instrument flight by USAF pilots,

2. (2) Problems encountered by USAF pilots while using HUDs during instrument flight.

CONCLUSIONS

HUDs have the potential to be used as a primary flight reference system. However, problems and ambiguous areas remain to be resolved prior to the development

REQUESTING AGENCY			
USAFIFC (11) 18 Aug 76			
BEGINNING DATE	COMPLETION DATE	TEST AIRCRAFT	TEST SITE
May 1976	August 1976	None	Randolph AFB TX 78148

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DISTRIBUTION	ATTACHMENTS
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of hardware, symbology, procedures, and techniques for total HUD use in IMC flight environment.

The majority of the pilots surveyed stated a cross-check with the instrument panel was constantly required; therefore, HUDs are not being used as a totally primary flight reference system.

None of the HUDs covered in this survey possessed an adequate failure monitor system. Erroneous information could be displayed without the pilot's knowledge unless a constant instrument panel cross-check was maintained.

All flight information is not available on the HUDs. Examples of missing information include TACAN, DME, bank scales, and engine information.

A potential problem appears to be the distracting and sometimes disorienting effect, due to constantly changing external visual environment, of flying the HUD in IMC.

In addition to the problems associated with the HUD itself, there is scarce information regarding techniques and procedures for use of the HUD in IMC. The majority of surveyed pilots use either the all-weather section of their Dash-One and/or the standard instrument procedures contained in Air Force Manual AFM 51-37. Neither of these documents deal specifically with IMC HUD flying; therefore, the procedures, techniques, and instructional methods are not standardized for HUD flying.

Although HUD symbology has become fairly standardized for use as a weapons delivery system, standardization for use as a primary flight reference is still lacking. Without procedures and techniques, instructional methods cannot be established and published. Extensive research is required to determine if the HUD can be used as a primary flight reference system. In the absence of this research, the full potential of head-up display may never be realized.

RECOMMENDATIONS

A pilot factors program to determine how HUDs should be used during instrument conditions is vitally needed. The objectives of this program must include, but not necessarily be limited to, the following areas:

a. Should HUDs be used as a primary flight reference system under IMC?

b. What symbology and format is required if the HUD is used as a primary flight reference system?

c. What procedures and techniques should be used for the HUD under IMC conditions?

The pilot factors investigation should be conducted in three phases. Phase I will first determine if the HUD can be used as a primary flight reference system and Phase II will determine the essential symbology for the HUD

if it can be used as primary flight reference system. Phase III will determine the procedures and techniques needed to fly the HUD in instrument flight.

This program should produce a data base from which fundamental information may be drawn to establish the optimum configuration/format and also provide the procedures, techniques, and general information necessary for inclusion in Air Force Manuals and Regulations.

DESCRIPTION OF THE TEST SYSTEMS

The HUD provides the pilot with flight information in symbolic form on a combiner glass directly in the pilot's forward field of view. The display is aligned with the aircraft flightpath and is optically focused at infinity. Symbology is formed on the combiner glass through a series of collimating lenses. HUD symbology is available for en route navigation, terrain following, attack, and landing phases of flight depending on the aircraft. The pilots surveyed in this evaluation are currently flying the F-111D, A-7D, and F-15 aircraft.

F-111D HEAD-UP DISPLAY SYSTEM (SU-46/SU-47)

The head-up displays provide each crew member with tactical information for weapons delivery and with primary flight reference data. Each head-up display consists of a combining glass, cathode ray tube, and controls. The combining glass is an optical glass which prevents distortion. This glass projects the video symbology symbols, words or numerals, which are received from the cathode ray tube (CRT). The symbology is focused at infinity for optimum compatibility with the crew members' outside view. A cathode ray tube is located in each HUD display unit. The CRT changes the electrical signals received from the vertical situation display, multi-sensor display, and integrated instrument display into the video symbology. The total field of view of the HUD system is $\pm$ 10° in azimuth and + 5 and - 15° in elevation. The symbology appears on the display image or in one or more of the ten location zones on the lower half of the display (figure 1).

Flight Reference Data Symbology:

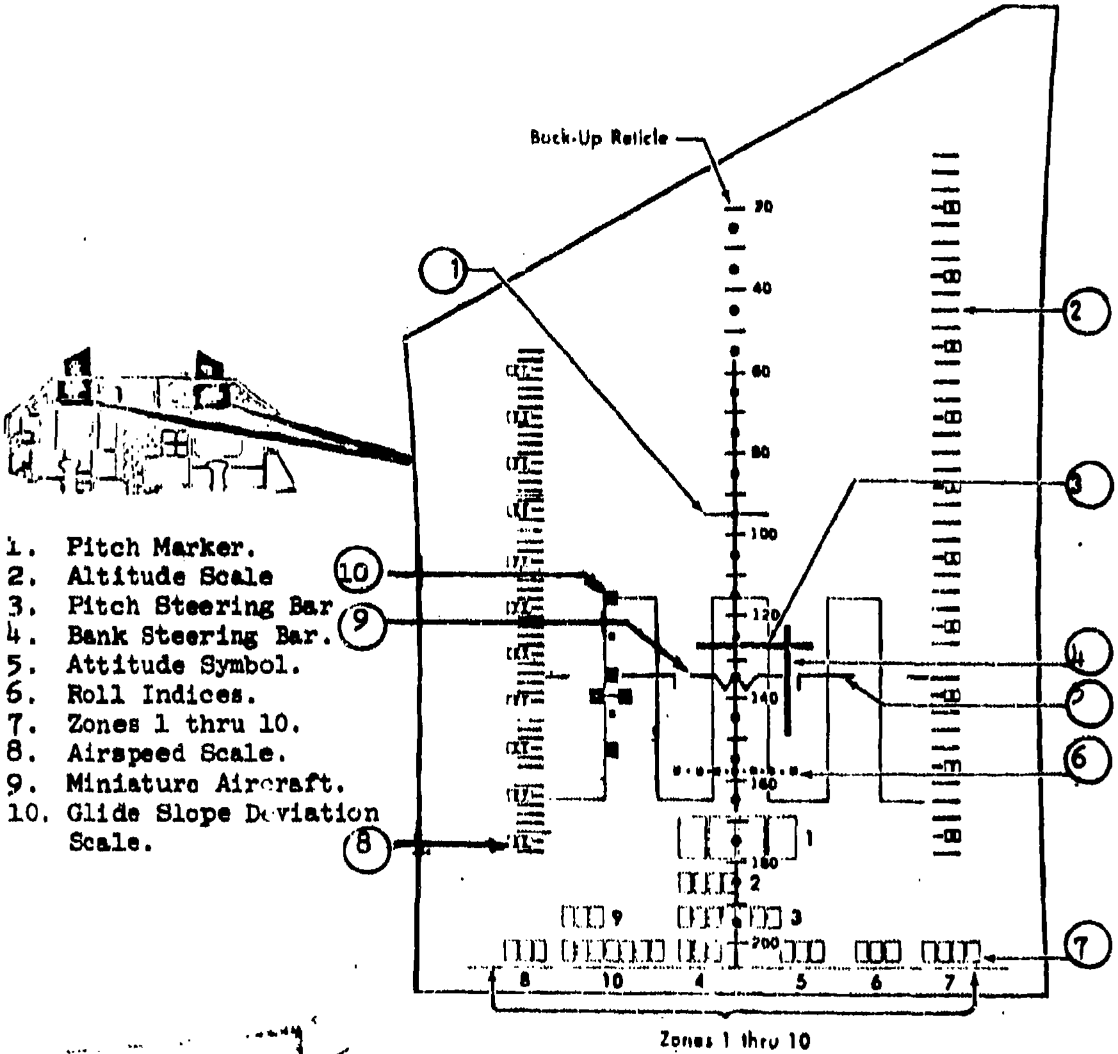
The flight reference data symbology (except lubber line and roll indices) is displayed in all modes of operation.

. Aircraft symbol - The miniature aircraft is fixed at the boresight reference which is 5° below fuselage reference line.

. Attitude symbols - The attitude symbols, adjacent to the miniature aircraft, display roll and pitch information.

. Steering bars - Pitch and bank steering bars are referenced to the miniature aircraft. The center of the miniature aircraft is the zero reference point.

Head-Up Display



1. Pitch Marker.
2. Altitude Scale
3. Pitch Steering Bar
4. Bank Steering Bar.
5. Attitude Symbol.
6. Roll Indices.
7. Zones 1 thru 10.
8. Airspeed Scale.
9. Miniature Aircraft.
10. Glide Slope Deviation Scale.

Figure 1.

. Glide slope deviation scale - The scale, located on the left side of the display, has a movable marker. The moving marker is displayed in the upper half of the scale when the aircraft is below the desired glide slope, and vice versa.

. Lubber line and roll indices - The lubber line and roll indices are displayed during takeoff and landing modes. Roll indices are spaced horizontally every 5°, and pitch markers at ± 5° from the boresight reference line.

. Altitude scale - The altitude scale has a fixed index line indicating the aircraft's present altitude. The letters RAD or BARO are displayed below the scale to indicate the source (radar or barometric) of the altitude signal.

. Airspeed scale - The airspeed scale has a fixed index line indicating the aircraft's present airspeed. The letters CAS are displayed below the scale.

A-7D HEAD-UP DISPLAY, AN/AVQ-7(V)

The A-7D HUD supplies flight information in symbolic form on a combiner glass in the pilot's forward field of view. The display is in line with the aircraft flightpath and is optically focused at infinity. Symbology is formed on the combiner glass through a series of collimating lenses. A-7D HUD symbology is available for en route navigation, terrain following, attack, and landing phases of flight.

The combiner glass has two positions, forward and aft. The forward position is used for en route navigation, the aft position for attack and landing. The aft position moves the apparent position of the display downward to align it more closely with the pilot's field of view during attack and landing.

A scales switch on the HUD control panel also controls portions of HUD symbology. With the switch placed in the SCALES position, the HUD displays altitude, indicated airspeed, vertical velocity and magnetic heading.

Symbology Functions: (see figure 2)

Horizon and Flightpath Angle Lines:

The horizon and flightpath angle lines represent the horizon and each 5° of pitch angle between plus and minus 90°. Not less than two nor more than three lines are displayed in the instantaneous field of view. Positive pitch lines are solid lines and appear above the horizon line. Negative pitch lines are dashed lines and appear below the horizon line. Each line is numbered, except the horizon line. Negative pitch line numbers are preceded by a minus sign. The HUD displays aircraft pitch and roll information

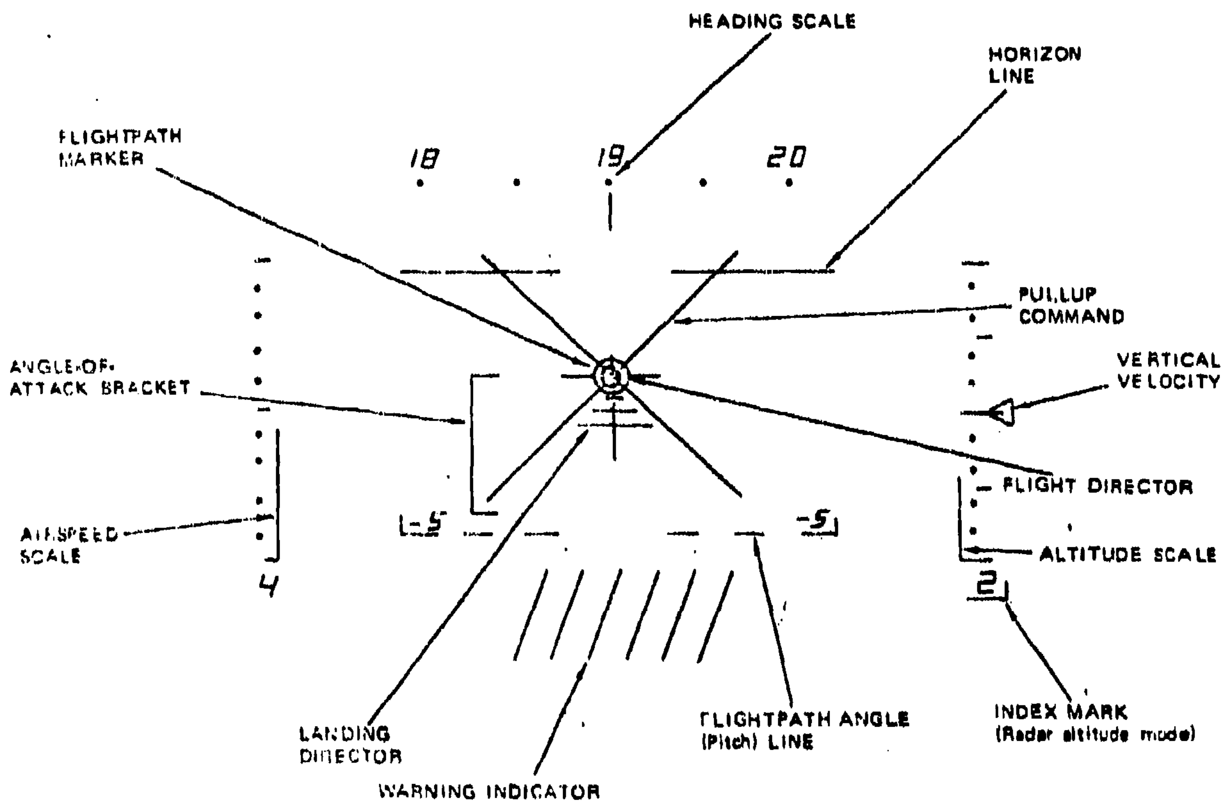

HEADING SCALE
HORIZON LINE
FLIGHTPATH MARKER
18
19
20
PULLUP COMMAND
ANGLE-OF-ATTACK BRACKET
VERTICAL VELOCITY
FLIGHT DIRECTOR
AIRSPEED SCALE
-5
-5
ALTITUDE SCALE
4
2
INDEX MARK (Radar altitude mode)
LANDING DIRECTOR
FLIGHTPATH ANGLE (Pitch) LINE
WARNING INDICATOR

Figure 2.

upon receipt of valid NAV WD computer inputs. The flightpath angle and roll display are the same in all modes of operation.

Flightpath Marker:

The flightpath marker represents the aircraft velocity vector in all modes within the capability of display on the combiner glass and is positioned by the NAV WD computer. The velocity vector represents the point toward which the aircraft is flying at all times. When the generated information is invalid or if data is not present or is incorrect; the HUD automatically uses the Doppler drift angle input to position the flightpath marker in azimuth, and uses the angle-of-attack transducer to position the flightpath marker in elevation.

Flight Director:

The flight director symbol indicates horizontal and vertical steering error information in terrain following and navigation modes with respect to the flightpath marker. In terrain following, the radar positions the flight director vertically to indicate climb or dive commands and the NAV WD computer positions the director horizontally, indicating heading steering error. In the navigation modes, the NAV WD computer positions the flight director symbol to indicate steering error.

Magnetic Heading Indicator:

All magnetic headings are displayed on a moving tape across the top of the HUD. The heading indication is poistioned by NAV WD computer inputs and displays a total of 20° of heading at any given time.

Landing Director:

The landing director consists of the landing director dot (identical to flight director) and three perspective lines which are displayed in the landing mode only and are positioned vertically and horizontally by raw ILS localizer and glide slope signals. An azimuth reference line, perpendicular to and bisecting the bottom perspective line, is displayed in the landing director. When the aircraft is on the proper flightpath ith respect to localizer and glide slope, the landing director dot is centered within the flightpath marker and the perspective lines are all superimposed upon one another in the center of the flightpath marker. Receipt of an unreliable localizer or glide slope signal causes the HUD to remove the landing director symbol. The landing director dot is positioned by the flight director computer to indicate steering commands.

Altitude Scale and Indicator:

Barometric or radar altitude is displayed on a thermometer-type scale on the right side of the HUD. A full scale indication represents 1,000 feet.

The number at the bottom of the scale indicates 1,000-foot increments. The NAV WD computer provides barometric altitude inputs based on barometric pressure set in for the FLY TO destination. In flying to a MARK, altitude is based on a mean sea level pressure of 29.92 inches of mercury. The radar altimeter provides altitude information for modes below 5,000 feet. Radar altitude is displayed on the HUD only when the BARO ALT/RDR ALT switch is in the RDR ALT position. An index mark is displayed beneath the altitude number to indicate the radar altimeter mode.

Airspeed Scale and Indicator:

Indicated airspeed is displayed on a thermometer-type scale on the left side of the HUD. A full-scale indication represents 100 knots. The number at the bottom of the scale indicates 100-knot increments. The Air Data Computer provides the airspeed input.

Vertical Velocity Indicator:

The aircraft's vertical velocity is displayed by a triangular-shaped symbol along the altitude scale. The top half of the scale represents up to 1,000 feet per minute of descending velocity. The position of the vertical velocity symbol is controlled by the NAV WD computer.

Angle-Of-Attack Indication:

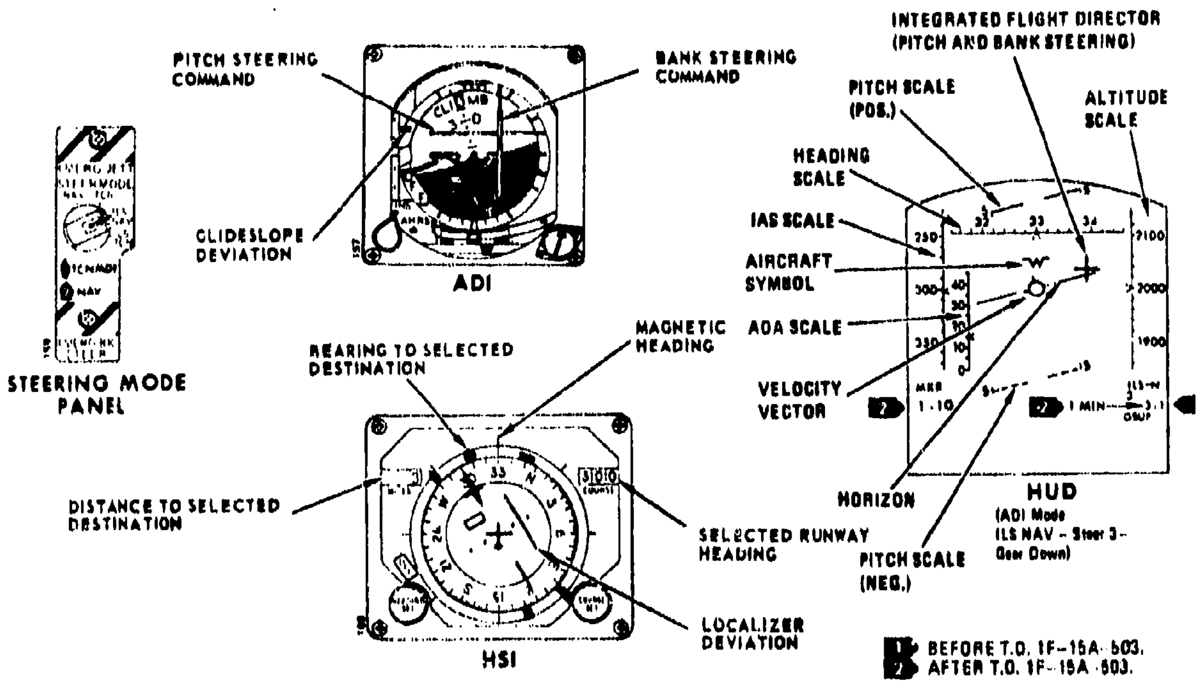
The angle-of-attack indicator is a bracket positioned to the left of the flightpath marker. The indicator bracket is present in all modes when the angle-of-attack exceeds 14 units. The angle-of-attack bracket displays the error from landing AOA (17.5 units) with respect to the FPM. In landing, the angle-of-attack is at the optimum approach value (17.5 units) when the bracket is centered opposite the wing of the flightpath marker. When the angle-of-attack is too high (aircraft slow), the center of the bracket is above the wing of the flightpath marker. The angle-of-attack bracket is driven by the angle-of-attack transducer.

F-15 NAVIGATION HEAD-UP DISPLAYS (Figures 3 and 3a)

The HUD is located on the main instrument panel and displays the following aircraft parameters in all modes of the avionics system: magnetic heading, calibrated airspeed, barometric altitude, velocity vector, flightpath, pitch and roll, and (in air-to-air modes) aircraft mach. On aircraft after T.O. 1F-15A-503O, the aircraft load factor to the nearest tenth of a G is displayed in all modes. These aircraft are also equipped with a provision to cage the velocity vector symbol in the ADI mode. When the ADI mode is initially selected, the velocity vector is positioned at the correct position. When a large crosswind exists, the velocity vector and pitch scale are displaced to the edge of the HUD. Depressing and releasing the stiffen/reject button on the throttle centers the velocity vector and pitch scale in azimuth. A subsequent depression frees the symbols in drift. The caged velocity vector pulses in the same manner as a degraded velocity vector. In all modes the

ILS/NAV AND ILS/TACAN MODE DISPLAYS

ILS/NAV



ILS/TACAN

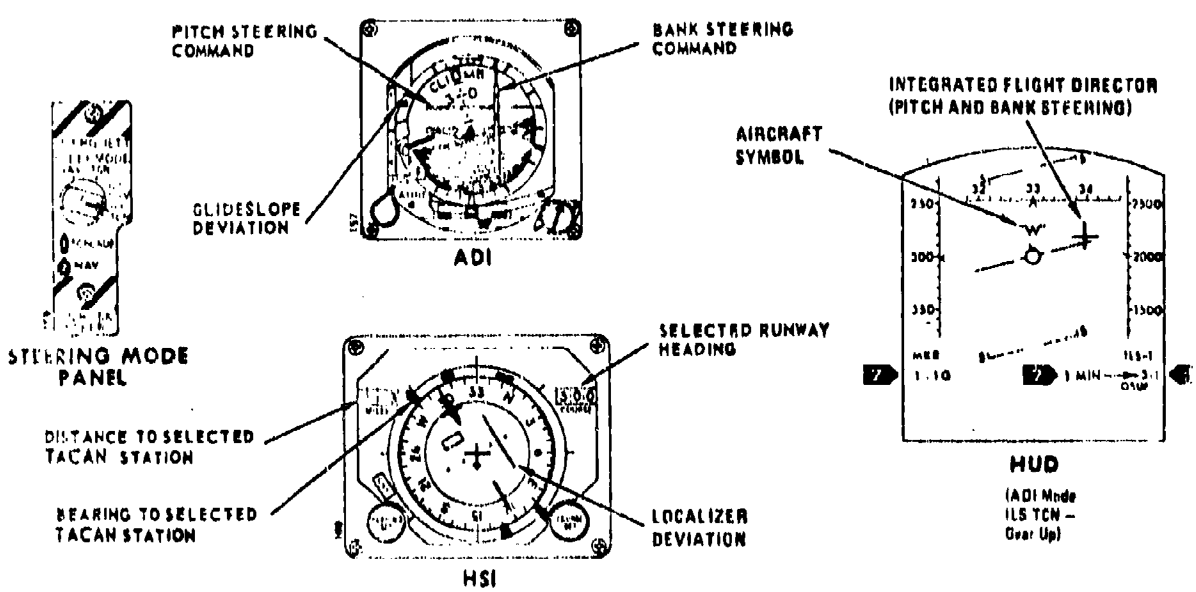
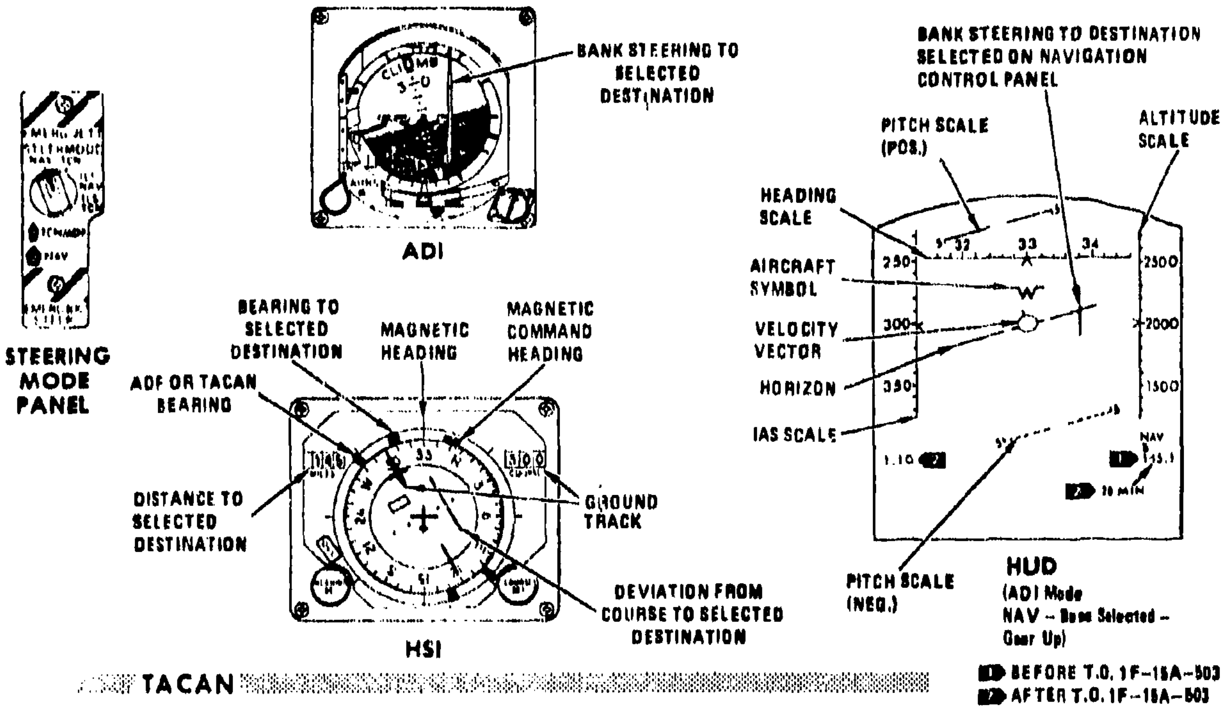


Figure 3.

TACAN/NAV MODE DISPLAYS

NAV



TACAN

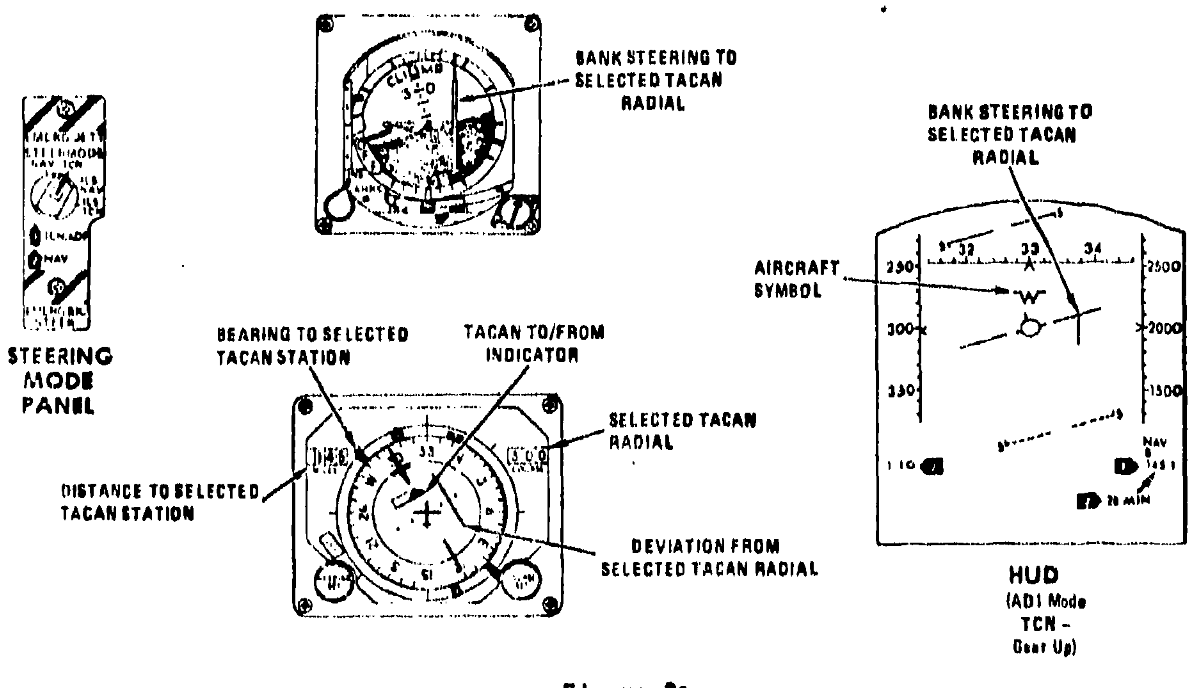


Figure 3a.

heading, airspeed and altitude symbology can be removed by placing the HUD symbol switch on the HUD control panel to the reject position. In addition to the flight parameters, the HUD displays navigational data if the avionics system is in the ADI mode. In NAV (navigation) mode, in addition to the flight parameters, the HUD displays bank steering to the destination selected. In TACAN mode, the HUD displays are the same as in NAV mode except the bank steering displayed is to the selected TACAN radial, the distance displayed is to the TACAN station, and destination is not displayed. In ILS/NAV and ILS/TCN (instrument landing set) modes, in addition to the flight parameters, the HUD displays the following: bank and pitch steering bars for approach and landing on runway destination, distance to destination (in ILS/NAV) or TACAN station (in ILS/TCN), the steering mode selected, and the GSUP and GSDN symbols for glide slope steering. Also, when the steering mode knob is in either the ILS/NAV or ILS/TCN mode and the aircraft passes over the outer marker or middle marker beacon, the beacon light will flash and a MKR will flash on the HUD. When the gear is down, in ADI mode, angle of attack data in cockpit units is displayed on the HUD, and the altitude and airspeed scales are expanded.

DATA COLLECTION

A questionnaire (attachment 1) was sent to A-7, F-15, and F-111D pilots throughout the Air Force. The survey solicited responses from both active duty and Air National Guard units. The units surveyed are presented below:

A-7 Units - 355th Tactical Fighter Wing, Davis Monthan AFB AZ
23rd Tactical Fighter Wing, England AFB LA
354th Tactical Fighter Wing, Myrtle Beach AFB SC
150th Tactical Fighter Group, Albuquerque ANG NM
140th Tactical Fighter Wing, Buckley ANG, CO

Total pilots responding - 87

F-15 Units - 1st Tactical Fighter Wing, Langley AFB VA
58th Tactical Fighter Wing, Luke AFB AZ

Total pilots responding - 18

F-111D Units - 27th Tactical Fighter Wing, Cannon AFB NM

Total pilots responding - 18

The total number of pilots responding to the survey was 123. These pilots represent a substantial percentage of Air Force pilots flying head-up display. They also represent a cross-section of experience within the Air Force in regard to years rated, total flight time, aircraft flown, and HUD experience.

TEST RESULTS AND DISCUSSION

Analysis of the subjective data will be addressed by HUD type.

A-7 HUD

The majority of the A-7 pilots surveyed stated the HUD could be used as a primary flight reference during all phases of flight. Takeuffs and instrument approaches and landings were the only segments which received significant negative comments due to some non functioning items while pressure remained on the landing gear. Eighty five of eighty seven pilots reported their HUD enhanced their ability to fly instrument approaches, but only 16 preferred to use the HUD as the primary system during instrument approaches in IMC. Of the remainder of the pilots surveyed, four preferred the instrument panel as primary, while 67 preferred a combination of HUD and instrument panel during such approaches.

The contradiction between reported capability and preference of use is explained by certain characteristics specific to the A-7 HUD. Although the A-7 HUD can be utilized as a primary system, it lacks necessary navigation information (bearing and DME) and a desired bank scale.

The A-7 pilots reported the HUD was considered to enhance the pilot's capability to fly instrument approaches, but due to the various types of HUD failures, most pilots were reluctant to use it totally until on short final. Failures where erroneous or failed information is displayed and cannot be determined from the HUD itself, present a potentially dangerous situation especially when the instrument panel is not cross-checked. With an insidious failure, erroneous information could be followed to a catastrophic conclusion. When a HUD failure is determined, the adjustment to the instrument panel requires excessive time and may cause a potentially dangerous situation. All of the pilots surveyed, even those who considered the HUD satisfactory as a primary display, stressed a good cross-check between the HUD and instrument panel was a necessity to insure a safe flight regime. Some of the other problems related by the pilots which were surveyed are as follows:

- In high crosswinds, HUD symbology is aligned with flightpath.
- Too much information was displayed with the scales and too little without the scales.
- It was very difficult to transition from the instrument panel to the HUD and back.
- Distracting, and sometimes disorienting effect of flying the HUD in IMC.
- Constantly changing external visual environment, such as changing ambient light and popping in and out of clouds, when viewed through the HUD caused spatial disorientation to some of the pilots.

No potential solutions were offered by the pilots surveyed, and the extent of the problems definitely require further study.

Generally, the pilots were extremely pleased with the A-7 HUD for instrument flying. The HUD was cited as giving a complete presentation of flight conditions in one place, reducing the cross-check to one small area. Because the aircraft velocity vector gives positive descent angles, precision and non-precision approaches were believed to be flown with more accuracy. When approaching a glide slope (2-1/2°), if the pilots set 2-1/2° on the velocity vector, then a 2-1/2° glide slope will be flown. Any correction to the glide slope can be accomplished with the velocity vector. Once the pilot is fully head-up, the transition from instrument flying to visual flying at breakout is much easier. The surveyed pilots also believed the velocity vector makes overall instrument flying easier; especially leveling off during climbs and descents and maintaining level flight.

The general instrument flying tasks were also considered easier with the HUD. The majority of pilots considered the HUD information presented (airspeed, altitude, reading, velocity vector, AOA) provided the capability for more precise flying with rapid trend information available so minor corrections can be made faster and easier.

F-15 HUD

The majority of F-15 pilots surveyed stated the HUD could be used as a primary flight reference in all the phases of flight. Takeoffs, instrument approaches, and landings received negative comments from only three pilots. Seventeen pilots considered the F-15 HUD enhanced their ability to fly instrument approaches, but only four preferred to use the HUD as the primary system during instrument approaches in IMC. The remainder of the pilots surveyed (14) preferred a combination of HUD and instrument panel during such approaches.

The small contradiction between capability and preference of use is explained by certain characteristics of the F-15 HUD. Although the HUD can be utilized as a primary system, it lacks DME information for TACAN and no actual bank scales are available.

NOTE: DME or "distance to go" was available on earlier aircraft. This feature has been changed to "time to go."

Pitch and bank steering bars are available for approaches, but the information presented was not considered sufficient for IMC approaches until they were very close to glide slope and localizer. The subject pilots indicated that, without some type of raw data or cross-checked information from the instrument panel, they would not be sure if the HUD information was accurate and valid. Some of the pilots stated that if the pitch and bank steering bars were followed too far out from the runway, the aircraft would "S" down the beam. Specific reasons for the "S"ing were not

given. Two types of HUD failure may preclude its use as a primary approach system in IMC until on short final. Any insidious failure where erroneous or failed information cannot be determined from the HUD itself presents a potentially dangerous situation if the instrument panel is not cross-checked. If the failure is insidious, erroneous information could be followed. Also, if a HUD failure is determined, the time to switch to the instrument panel could require excessive time and may cause a potentially dangerous condition. The pilots surveyed stressed that a good cross-check between the HUD and instrument panel was a necessity to insure safe flight.

Only two additional problems were related by the pilots surveyed. At times during ILS approaches with all the scales and information being displayed, the HUD appeared cluttered. This cluttering could cause problems in assimilating the displayed information and acquiring all the outside visual cues available, especially during the final portion of the approach. A more serious potential problem was the distracting and sometimes disorienting effects of flying the HUD in IMC. The constantly changing external visual environment was reported by approximately half the pilots surveyed to be at least distracting. However, no solutions were offered to relieve the potential problem areas, and the extent of the problems may require further study.

Despite these problems, the pilots were extremely pleased with the F-15 HUD for instrument flying. The aircraft velocity vector, AOA, and ease of cross-checking the HUD display itself were cited as the most beneficial aspects of the HUD. The velocity vector was especially well praised both for overall instrument flying and instrument approaches. In general, they believed the velocity vector made it very easy for leveling off during climbs and descents and for maintaining level flight. More important was the emphasis placed on the velocity vector for setting a specific glide path during an approach. The method presented by the pilots was to set the velocity vector on the desired flightpath angle and by maintaining the velocity vector, a constant glide slope would be flown. In using this method, the flightpath angle was controlled by changing velocity vector rather than with direct pitch adjustments. With this technique, once the pitch and bank steering bars were centered and the HUD information verified, the pilots normally went totally head-up to acquire the runway much earlier than during a normal instrument approach. This made the final approach and flare easier, safer, and more precise than when flying with only the instrument panel.

In general, instrument flying was considered easier with the HUD. The majority of pilots considered the variety of HUD information presented (airspeed, altitude, heading, velocity vector, AOA) provided rapid trend information allowing minor corrections to be made faster and easier. This greatly increased the flying precision.

F-111D HUD

Table 1 presents the ratings of F-111D pilots regarding the use of their HUD as a primary flight reference for various mission segments.

TABLE 1

Number of F-111D Pilots Considering HUD as Unacceptable for Primary Flight Reference for Various Mission Segments is listed in the table below. There were 18 subject pilots.

13 - Takeoff	9 - Cruise	14 - Landings
13 - Climb out	12 - Descent	18 - Go-Around
12 - Leveloff	11 - Instrument Approaches	

As shown in Table 1, the highest number of pilots who considered their HUD acceptable as a primary flight reference was for the cruise segments (50%). None of the surveyed pilots reported that they utilized the HUD as a primary display or in combination with the instrument panel when flying instrument approaches in IMC. All 18 pilots reportedly used the instrument panel without reference to the HUD during most of the flight regime. Only one pilot considered the HUD to have enhanced his ability to fly instrument approaches and this was in using the HUD cursor to find the runway.

The reasons given for the widespread negative attitude regarding IMC HUD flying were quite varied. Sufficient scaling was not available for precise pitch control and the scale itself was ill-defined and hard to read. Different pitch indications were at times presented on the vertical situation display (VSD) and HUD making it difficult for the pilots to determine the actual aircraft pitch. The surveyed pilots reportedly placed more reliance on the VSD and therefore disregarded the pitch information on the HUD. Small aircraft pitch changes were said to cause large excursions from the horizon reference on the HUD and the pitch scale was considered too sensitive to minor airspeed changes.

The airspeed and altitude scales were reported blurry and difficult to read with most of the other symbology also being considered somewhat blurred and difficult to read accurately. The HUD symbology was also reported to obscure forward vision and external visual cues. These problems may be directly related to the HUD field of view (FOV), symbology color, and symbology light intensity.

From the pilots' comments it was evident that to see all the HUD symbology, head movements were required. It is not known if this problem is due to the actual FOV of the HUD or its position in the aircraft relative to the design eye point. In any event, the FOV was considered by the pilots

as excessively small. Additionally, whenever the symbology light intensity was set low, the symbology was difficult to read. If the intensity was increased, the symbology became blurred. Also, at higher intensity settings, the symbology appeared so bright as to obscure forward vision and cause a distinctive green glow. This green glow reflected off the windscreen and was very distracting. The reflection also destroyed night vision.

Not all parameters are available on the HUD for actual flight in IMC. The deficiencies include rates of descent and climb and no heading references. This lack of information required a high degree of HUD/instrument panel cross-checking in addition to engine instrument cross-checks. The eye movements from the HUD to the instrument panel were said to be excessive. The majority of pilots believed it was much easier to cross-check the instrument panel itself.

Only two positive comments were presented by the surveyed pilots regarding IMC instrument flying. The HUD made a good secondary reference by using the cursor to find the runway during IMC approaches and permitted head-up transition earlier. However, the only time the pilots could go head-up earlier than normal during an IMC approach was when the steering bars were centered and cross-checked for validity and accuracy. Although the early head-up procedure was stated by some of the pilots, it was not generally accepted because of a lack of faith in the validity of the flight reference information presented on the HUD.